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(54) METHOD OF FORMING A TUBULAR WORKPIECE WITH A BEND

(71) We, DEUTSCHE BABCOCK & WILCOX AKTIENGESELLSCHAFT, of 375, Duisburger Strasse, 42 Oberhausen/Rhld. Germany, a corporation organised under the laws of the Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of forming a tubular workpiece with a bend.

When tubes are bent on machines with application of heat, only an annular zone may be brought to a hot profiling temperature, and the tube is deformed in some cases by individual steps and in other cases continuously. The surroundings of the bending region are cooled, so that at the position of the bend itself an ovality of the tube bend may be prevented by the so-called supporting effect of the cooler, non-deformable surroundings. According to the existing specifications, particular values for such ovality may not be exceeded, which in the case of bending with small ratios of bending radius to the outer diameter of the tube to be bent may not be attainable when earlier processes are employed, so that the development both of the "Hamburger" and also of the "Inductive Tube Bending" processes took place. Processes with gas ring burners or chamber furnaces, which heat only a zone of a tube, work also on the same principle. In the employment of these processes it became apparent, however, that damage to the tube material can occur at the outer bend, in consequence of factors restricting elongation. In other processes, during the continuous bending a counter-pressure is applied to the tube against the direction of feed of the tube. However, this principle has generally only been employed for tubes of diameter up to 460 millimetres, since in other cases machine dimensions may be required which are not an economic proposition.

Furthermore, with the described machines, in particular in the case of bends beyond 90°, supporting tools may also be necessary, which can make the process uneconomic. Particularly in high pressure and super-heated steam lines in the chemical industry, and also in power stations consuming nuclear fuels, lines of large internal diameter and large wall thicknesses may be necessary. These may considerably exceed the value of 460 millimetres, and nowadays may even reach a magnitude of 1000 millimetres internal width at an R/d value of 1.5 and a d/s value of 10, where d represents the tube outer diameter, s the tube wall thickness, and R the bending radius. Because of the high cost of the material, oversizing may be a substantial cost factor, and installations for the production of Hamburger bends rather scarce, so that pressings may have to be put together using expensive weld connections to produce the required tube bends.

For the production of tube bends, the thickenings required to impart adequate strength and permissible thinnings of the tube wall are specified accurately by the inspection authorities. According to these authorities, the required thickening of the inner bend may be represented by

$$\frac{4\frac{R}{d}-1}{4\frac{R}{d}-2}=fi,$$

and the permissible thinning of the outer bend by

$$\frac{4\frac{R}{d}+1}{4\frac{R}{d}+2}=fa,$$

where fa and fi are the factors by which the wall thickness of the tube before deformation

[*Price 33p*]

is multiplied to give the wall thickness after deformation, fi is always greater than 1, and fa always smaller than 1. In the formulae, R/d is the value of the bending radius divided by the outer diameter of the tube to be bent. As the ratio of R to d becomes smaller, fi becomes greater, and fa smaller.

These formulae of membrane theory show that at positions of tube bends much thicker tubes must be employed for their production, and that additional welding seams and/or a considerable excess consumption of material becomes necessary. Thus for example, tube bends produced in the "Hamburger" tube bend process, in which with a circular cross section a wall thickness is generated which is completely uniform over the circumference, consume much more material than the specified thickening of the inner bend requires. When a frequently occurring value of R/d of 1.5 is employed, this is according to the above formula an increased material demand of 25 per cent, which is present also in the outer bend, which, however, according to the second formula could, if desired, be thinner by 12.5 per cent.

Particularly in the case of thick-walled tubes of large diameter and small bending radius, this gives rise to a greatly increased material consumption, connected with high costs with expensive materials, such as are necessary in super-heated steam lines of power stations with petrified and nuclear fuels of high performance, or in the chemical industry where high alloyed fine steels are used. In the above example, in the case of Hamburger tube bends the increased consumption of material is 15.5 per cent, if a conventional value of d/s of 10 is accepted. What is more, the connection of over-sized bends of this kind with a subsequent tube may give rise to undesired tensions, while the formation of a transition between tube lengths by mechanical working may be expensive and difficult, and a weld connection may be unsightly.

According to the present invention, there is provided a method of forming a tubular workpiece with a bend, comprising the steps of heating a portion of the circumference of the workpiece at a bending region of the workpiece to a first temperature such as to render that portion deformable by a hot working process, maintaining the remainder of that circumference at a second temperature below the first temperature, the difference between the first temperature and the second temperature being substantially in the range of 100°C to 500°C, and so deforming the workpiece to produce a bend at the bending region that the portion includes the innermost part of the bend.

Suitably, the portion comprises three quarters of the circumference.

Conveniently, the workpiece is of steel and the heating step comprises the step of heating the portion to a temperature in the range of 850°C to 1200°C.

In one method, the workpiece is of steel, the mean temperature of the remainder being 650°C and the highest local temperature in the portion being 1100°C during the deforming step.

Suitably, heating means comprising an inductor are employed to carry out the heating step.

Conveniently, the inductor is provided with yoke laminations to intensify said portion heating, and preferably a part of the inductor is free from the presence of yoke laminations, that part of the inductor being provided to heat the remainder of the circumference; further preferably the yoke laminations occupy substantially half of the circumference of the inductor.

Expediently, the yoke laminations are arranged symmetrically about a bending plane defined at the bending region, and preferably the inductor comprises a surface heating inductor to heat different longitudinal sections of the workpiece with different intensities.

The inductor may comprise a plurality of helical turns of electrically conductive material.

Suitably, at least two individual such inductors are provided to heat respective portions of the workpiece, which are mutually spaced in the direction of the longitudinal axis of the workpiece, and preferably said two inductors are connected individually to respective sources of alternating current at respectively different frequency.

Conveniently, the yoke laminations of successive ones of the inductors occupy successively greater proportions of the circumferences of the respective inductors.

Suitably, heating means comprising at least one burner are employed to carry out the heating step and preferably a series of inductors cooperate with the burner or burners.

The method may comprise the step of so mounting the workpiece on a support that the heating means are received within the workpiece.

The method may comprise the step of so locating the workpiece that the remainder of the circumference at the bending region is spaced further than the portion from the respectively nearest part of the heating means.

Preferably, the deforming step is so carried out that the ratio of the wall thickness of the portion of the circumference after the deforming step to the corresponding value before the deforming step is at least

$$\frac{4\frac{R}{d}-1}{4\frac{R}{d}-2};$$

and that the ratio of the wall thickness of the remainder after the deforming step to the corresponding value before the deforming step is at least

$$\frac{4\frac{R}{d}+1}{4\frac{R}{d}+2};$$

where R is the radius of the bend, and d is the external diameter of the workpiece.

Two methods exemplifying the present invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 shows a schematic perspective view of a device for carrying out one method exemplifying the present invention and provided with pre-heating inductors of different yoke coverings and different frequency; and

Fig. 2 shows a schematic perspective view of a device with an inductor at the bending position, the inductor having yokes at the inner side of the bend, and a surface pre-heating inductor.

In the arrangement shown in Fig. 1, inductors with yoke coverings over different proportions of the circumference of each inductor, and thus of a tube 1, the inductors being of different frequency, are fitted on the tube 1 to be bent. In a pre-heating zone lie yokes 2, but only on a quarter of the circumference, while the parts of the tube disposed nearer to an intended bending position are covered for about a third of the circumference with yoke laminations 3, and those nearest to the bending position are covered for about half of the circumference with yoke laminations 4. The frequency supplied via lines 5 (1000 Hz) is in this case different from that supplied via the lines 6 (600 Hz). The bending of the tube takes place in a direction out of the plane of the drawing, towards the reader, in Fig. 1 and in Fig. 2.

In the arrangement shown in Fig. 2, a surface inductor is employed, which is larger in its middle zone 7 than in its outer zones 8. Yoke laminations 4 are fitted subsequently in the inner bend position.

With the illustrated devices, it is possible to undertake production by machine of tubes with bends of large diameters, and to obtain a controlled wall thickness pattern according to the specifications.

Since in bending a tube of uniform wall thickness is normally employed as the starting tube, the requirements of the formulae for permissible thinning and required thickening in outer and inner bends may not be possible to meet in all cases. The fulfilment of the requirement not to thin the outer bend impermissibly leads with tubes of uniform wall thickness to a substantially greater thickening of the inner bend than is required. From this follows an increased force requirement for the compressing of the enlarged cross section. However, it is not possible to use an indefinitely large force, since this might lead to a very great reduction in the resistance to deformation of the tube after bending. A tube bend which corresponds exactly to the formulae of membrane theory may, with judicious choice of variables, be produced using the illustrated devices, if for the bending a tube of non-uniform wall thickness is employed, the eccentricity of the tube being different from the R/d value of the bend. However, this may be inconvenient, in view of the necessity to connect the bent tube to a tube of uniform wall thickness, which may lead to similar problems as in the case of the too thick "Hamburger" tube bends, and may make additional weld seams necessary. An increased consumption of tube material may thus be deliberately put up with to retain the advantage of being able to bend continuously a whole length of pipeline, even in the case of three-dimensional bends. If it is desired to form in a tube several bends, all of which are disposed in one plane, then the thinnest tube wall should be arranged at the position of the inner bend, since seamless tubes in general are not of completely uniform wall thickness.

In one practical arrangement, the innermost part of the bend is heated to a first temperature in the range of 800°C to 1200°C, i.e. a temperature at which steel may conveniently be forged, while the outer quarter of the circumference of the tube is maintained at or below a second temperature of 700°C. In any case, the portion heated to the first temperature includes the innermost part of the bend. Where a workpiece of steel of usual quality is employed, a convenient upper limit for the second temperature is the "conversion temperature" or "transition temperature" of the steel, i.e. the temperature of the transition between the ferrite and austenite forms.

A continuous gradient in temperature from the innermost part of the bend to the outermost part of the bend is preferably maintained, for example from 1100°C to 650°C, in such a manner that the mean temperature value in the outer bend quarter of the circumference amounts to 650°C, while a value of 1100°C is the highest temperature value for the inner bend.

The heating means employed may comprise inductors and/or burners, which are fitted on the outside or inside of the tube and are connected to form a series along the path of the tube. They are controlled in accordance with the desired tube temperatures, so as to

heat the portion of the circumference of the tube to form the inner part of the bend and to control the temperature of the remainder of the circumference of the tube to form the outer part of the bend in accordance with the intensity and disposition of the inductors and/or burners. The bending itself (deforming step) is only begun when the desired pre-heating has taken place at all relevant positions of the tube and may be carried out by any suitable deforming means, for example of known kind.

It is expedient to arrange one or more pre-heating inductors or burners to precede the bending region in a path to be followed by the tube, so as to attain the necessary temperature at the bending region within a short time. It is ensured that the temperatures employed in such pre-heating are lower than those at the bending region and they are selected with regard to the tube material used.

It can be advantageous to bring about the intensification of the inductive performance of inductors and of the inductive field by the fitting of yoke laminations on the inductors adjacent the inner bend. The parts of the inductors surrounding the outer bend preferably carry no yoke laminations. A similar effect may be achieved if the part of the inductor surrounding the outer bend has a larger spacing from the nearest part of the tube surface than the part surrounding the inner bend has from its nearest part of the tube surface.

In Fig. 1 the pre-heating inductors of successively greater distance from the bending region are covered with field-intensifying yoke laminations over successively smaller proportions of the circumference, symmetrically about the bending plane, which is defined by guide means (not shown). The inductor shown at 7 and 8 in Fig. 2 is an inductor for surface heating, which pre-heats different longitudinal sections of the tube to different temperatures, but still symmetrically about the bending plane, and carries yoke laminations at its middle zone 7, on the inner bead side. It is expedient to incorporate at least two inductors constructed for operation at different frequencies in the apparatus.

In another arrangement (not shown), an inductor surrounding the tube in several helical turns is employed, which has on the inner side of the bend, arranged symmetrically about the bending plane, field-intensifying yoke laminations, which embrace about half of the circumference of the tube at the bending region and which are arranged on circumferential portions of the tube which become smaller in a direction away from the bending region.

With the described devices, operation can so take place that only one bending moment is applied at the bending region. In the bending region a temperature field is set up, which is so controlled that in the inner bend, for the purpose of the compression which has to take place there a zone of high temperature is generated. In the outer bend, the temperature remains so low that the tube in the outer bend region becomes elongated only slightly to the extent specified or perhaps even not at all. The forces necessary for producing the required elongation or tension then make possible the compression of the inner side of the bend. Thus, the necessity for the action of additional forces from outside to compress the inner bend part of the tube is avoided. Such action was, however, necessary in general in processes and devices previously employed. In the presently described process the material is treated with care, because a high temperature is applied only to that portion of the cross sectional surface of the tube which later becomes the inner bend, and the material is maintained relatively so cool at the remainder of the cross sectional surface, which later becomes the outer bend, that elongation and compression during the bending are in the specified ratio to one another, and an over-stressing of the material is avoided. The ratio of the area of the outer bend part of the cross sectional surface to the inner bend part is chosen to be equal to the ratio of the corresponding resistances of the respective parts of the tube to deformation. The following mathematical expressions apply to this manner of bending:

$$M_b > M_i + M_a$$

$$M_i < M_a$$

$$M_i = \sum \Delta F_i \cdot \sigma_{wi} \int_{T_1}^{T_2} r_i$$

$$M_a = \sum \Delta F_a \cdot \sigma_{wa} \int_{T_2}^{T_3} r_a$$

in which

M_b is the necessary bending moment;

ΔF_i represents a surface element of the bend part to be compressed—i.e. the inner bend part;

ΔF_a represents a surface element of the outer bend part;

r_i and r_a are the distances of the respective above mentioned surface elements from the bending axis;

$$\sigma wi \int_{T_1}^{T_2} \text{ and } \sigma wa \int_{T_2}^{T_3}$$

are the values of resistance to deformation of the respective surface elements which are mentioned in the definitions of ΔF_i and ΔF_a above and which are set in dependence upon the temperature obtaining in the element;

the range from T_1 to T_2 is the temperature range in which the tube is subjected to a compressive force during bending; and

T_2 to T_3 is the temperature range in which the tube is subjected to a tension force during bending.

T_1 thus represents the highest, and T_3 the lowest temperature of the tube around the periphery at the bending region.

Since the resistances to deformation alter also with the speed of deformation, the bending power and thus also the bending speed can be calculated in dependence upon the applied heating power.

The generation of a temperature gradient, to fall from high values in the inner part of the bend to low ones in the outer part of the bend, is possible by taking steps to raise the inductive performance at the places to be heated more strongly, and converse steps at the places of low desired temperature. This may be done for example by means of an inductor equipped on one side with yoke laminations.

The inductive heating takes place at a depth in the tube wall determined in dependence upon the chosen frequency. The heat is further transported from its position of inductive generation, by thermal conduction. Only a limited power per unit surface area may in practice be applied, to avoid overheating. Especially at large wall thicknesses and/or large bending speed therefore, it may be advantageous to pre-heat in particular the eventual inner bend part before it reaches the position where bending takes place. The inner bend part is to be brought to a high temperature, since also the characteristic of the inductive heating alters with temperature. This pre-heating can likewise be carried out by one or more inductors, the inductor at the bending region itself being covered for example with yoke laminations over about half of the tube circumference, while the pre-heating inductor connected in front of it is provided with yoke laminations symmetrically to the inner bend for example only over one third of the circumference, and the one disposed in front of the latter for example only over one quarter of the circumference. If electric power is not available, the pre-heating can take place by means of gas burners. In any event, gas burners may be used to co-operate with inductive heaters. The employment of gas burners is particularly useful when heating is to take place also from the inside of the tube, to achieve a very uniform temperature over the wall thickness in the bending zone, at a large wall thickness and/or a large bending speed. Mounting means (not shown) are then provided, so to mount the burners and/or inductors on a support (not shown) as to permit the tube to receive the burners and/or inductors within the tube.

Inductors for laminar heating can also be employed. Such inductors are shown in Fig. 2, and again are equipped in the innermost zone with yoke laminations.

When several inductors are employed, then a particular starting-up procedure and arrangement are used. The cold tube is pre-heated by the inductor at the bending region for example up to 500°C, while the pre-heating inductors are switched off. Then the first pre-heating inductor is switched on to heat at both places to 300°C, higher. Thus the bending region reaches for example 800°C, and the pre-heating region 300°C, whereupon the third (in the example the last) inductor is switched on. The deforming step is begun, when temperatures of for example 1050°C at the bending region and for example 600°C at the pre-heating position nearest to it are reached. A similar procedure is applicable when one or more gas burners are arranged outside and/or inside the tube. To achieve a uniform deep heating effect, after reaching the Curie point of the material an inductor fed with low frequency can be employed, with which the effect of the inductive heating is moved into a deeper zone of the tube wall.

The described process takes place by heating the tube, substantially without filling the tube or supporting the bending region by an internal mandrel.

WHAT WE CLAIM IS:—

1. A method of forming a tubular workpiece with a bend, comprising the steps of heating a portion of the circumference of the workpiece at a bending region of the workpiece to a first temperature such as to render that portion deformable by a hot working process, maintaining the remainder of that circumference at a second temperature below the first temperature, the difference between the first temperature and the second temperature being substantially in the range of 100°C to 500°C, and so deforming the workpiece to produce a bend at the bending region that the portion includes the innermost part of the bend.

2. A method as claimed in claim 1, wherein the portion comprises three quarters of the circumference.

3. A method as claimed in either claim 1 or claim 2, wherein the workpiece is of steel and the heating step comprises the step

of heating the portion to a temperature in the range of 850°C to 1200°C.

4. A method as claimed in either claim 1 or claim 2, wherein the workpiece is of steel, the mean temperature of the remainder being 650°C and the highest local temperature in the portion bei100 g°Cn1 asirpuu perature in the portion being 1100°C during the deforming step.

5. A method as claimed in any one of the preceding claims, wherein heating means comprising an inductor are employed to carry out the heating step.

6. A method as claimed in claim 5, wherein the inductor is provided with yoke laminations to intensify said portion heating.

7. A method as claimed in claim 6, wherein a part of the inductor is free from the presence of yoke laminations, that part of the inductor being provided to heat the remainder of the circumference.

8. A method as claimed in claim 7, wherein the yoke laminations occupy substantially half of the circumference of the inductor.

9. A method as claimed in any one of claims 6 to 8, wherein the yoke laminations are arranged symmetrically about a bending plane defined at the bending region.

10. A method as claimed in claim 9, wherein the inductor comprises a surface heating inductor to heat different longitudinal sections of the workpiece with different intensities.

11. A method as claimed in any one of claims 5 to 9, wherein the inductor comprises a plurality of helical turns of electrically conductive material.

12. A method as claimed in any one of claims 5 to 11, wherein at least two individual such inductors are provided to heat respective portions of the workpiece, which are mutually spaced in the direction of the longitudinal axis of the workpiece.

13. A method as claimed in claim 12, wherein said two inductors are connected individually to respective sources of alternating current at respectively different frequency.

14. A method as claimed in either claim 12 or claim 13, when appendant to claim 7, wherein the yoke laminations of successive ones of the inductors occupy successively greater proportions of the circumferences of the respective inductors.

15. A method as claimed in any one of claims 1 to 4, wherein heating means comprising at least one burner are employed to carry out the heating step.

16. A method as claimed in claim 15, wherein a series of inductors co-operate with the burner or burners.

17. A method as claimed in any one of claims 5 to 16, comprising the step of so mounting the workpiece on a support that the heating means are received within the workpiece.

18. A method as claimed in any one of claims 5 to 17, comprising the step of so locating the workpiece that the remainder of the circumference at the bending region is spaced further than the portion from the respectively nearest part of the heating means.

19. A method as claimed in any one of the preceding claims, wherein the deforming step is so carried out that the ratio of the wall thickness of the portion of the circumference after the deforming step to the corresponding value before the deforming step is at least

$$\frac{4\frac{R}{d}-1}{4\frac{R}{d}-2};$$

and that the ratio of the wall thickness of the remainder after the deforming step to the corresponding value before the deforming step is at least

$$\frac{4\frac{R}{d}+1}{4\frac{R}{d}+2};$$

where R is the radius of the bend, and d is the external diameter of the workpiece.

20. A method for forming a tubular workpiece with a bend, the method being substantially as hereinbefore described with reference to the accompanying drawing.

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Fig. 1

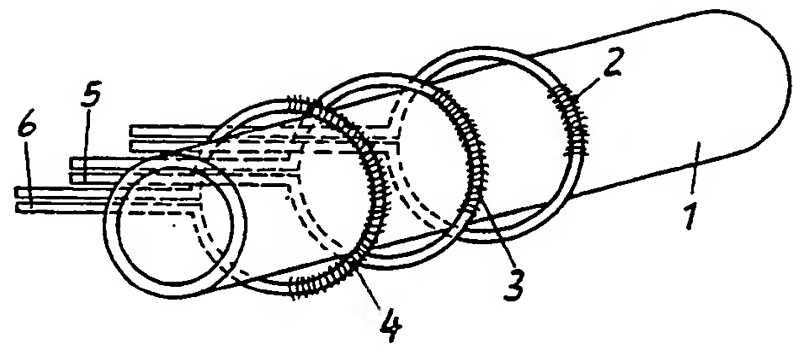

Fig. 2